U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

GROUND GUIDANCE SYSTEM TESTS

1. OBJECTIVE

The objective of the procedures ~~outlined in this MTP~~ is to ascertain such ground guidance system characteristics as accuracy and reliability. The procedures are conducted to ensure that ground guidance system design characteristics and limitations are adequate for the intended usage of the system.

2. BACKGROUND

The procedures outlined in this Materiel Test Procedure (MTP) describe ground guidance system tests (for pulsed radars, continuous wave radars, or phased array radars) which are applicable to complete guided missile weapon systems (missile systems). The ground guidance portion of the missile system is used to guide the missile toward an enemy target. The missile system can be used as either a defensive or an offensive weapon. When used in the defensive role, the purpose of the missile system is to defend an area against attack by enemy aircraft, missiles, ground forces, or sea forces. When used in the offensive role, the purpose is to destroy possessions of the enemy which are of value to him in the conduct of war. Because of the high accuracy and reliability requirements placed on ground guidance systems, engineering tests and evaluations are performed to determine limitations and other characteristics which may affect their operation.

Engineers and other personnel engaged in testing and evaluating ground guidance systems have developed over a long period of time, certain procedures for testing. Properly used, these procedures can determine the acceptability of a ground guidance system for an intended use. The ground guidance system must adhere to government and manufacturer's specifications to be accepted.

3. REQUIRED EQUIPMENT

a. Target Aircraft with Jamming Equipment
b. Balloons and Metal Foil Spheres
c. Signal Generators
d. Attenuators
e. Oscilloscopes
f. Vacuum Tube Voltmeters
g. Still and Time Coded Motion Picture Cameras
h. Oscillographs
i. Strip Recorders and Stop Watch
j. Phototheodolites and Associated Equipment
k. Telescopic Cameras and Associated Equipment
l. Corner Reflectors

4. REFERENCES

A. AFM 52-31, Guided Missiles Fundamentals, 1957.
B. Van Nostrand, D., International Dictionary of Physics and Electronics, D. Van Nostrand Company, Inc., New York, 1961.
C. MTP 5-2-530, Transmitter Tests
D. MTP 5-2-529, Radar Receivers
E. MTP 5-2-518, Antenna Subsystem Tests

5. SCOPE

5.1 SUMMARY

This MTP describes in general terms the tests required to determine and evaluate the technical performance of ground guidance systems.

The specific tests described below shall be conducted under procedures contained herein:

a. Maximum and Minimum Detection Ranges of Acquisition Radar Test - A test to determine the operating range of the acquisition radar, taking into consideration various conditions (e.g., peak transmitted power, antenna gain, cross section of target, ground clutter, jamming, etc.) which affect the operating maximum and minimum range of a radar.

b. Maximum Tracking Range Test - A test to determine the track radar's maximum tracking range in both manual and automatic tracking, under conditions similar to those mentioned in preceding step a.

c. Transfer to Track Time Test - A test to determine the average time required for the track radar to acquire the target in azimuth, elevation, and range once the acquisition radar relays some of the target coordinates to the track radar.

d. Transfer to track Accuracy Test - A test to determine the accuracy with which the acquisition radar operator can relay the target coordinates to the track radar.

e. Quality of Target Position information Supplied by Tracker Test - A test to determine the tracking bias by comparing the true target position with the position in which the radar "sees" the target.

f. Maximum Angle and Range Tracking Rates Test - A test to determine at what range rate and angular velocity of the target the radar will lose the target.

g. Human Engineering Test - A test to ensure that human engineering features (e.g., placement of controls, lighting, heating, air conditioning, etc.) are designed to permit a high degree of operator performance and comfort.

5.2 LIMITATIONS

The procedures in this MTP are not intended to be peculiar to testing specific ground guidance systems, They intentionally were made general to provide coverage for various types of systems. Special procedures are detailed in the applicable specifications, manufacturer's instructions, or Missile Purchase Descriptions (MPD's).

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6. PROCEDURES

6.1 PREPARATION FOR TEST

a. Select test equipment having an accuracy of at least ten times that of the function to be measured.

b. Record the following information:

1) Nomenclature, serial number(s), and the manufacturer's name of the test item(s)
2) Nomenclature, serial number, accuracy tolerances, calibration requirements, and last date calibrated of the test equipment selected for the tests.

c. Assure that all test personnel are familiar with the required technical and operational characteristics of the item under test, such as stipulated in Qualitative Material Requirements (QMR), Small Development Requirements (SDR), and Technical Characteristics (TC).

d. Review all instructional material issued with the test item by the manufacturer, contractor, or government, as well as reports of previous similar tests conducted on the same type of test items, and familiarize all test personnel with the contents of such documents. These documents shall be kept readily available for reference.

e. Thoroughly inspect the test items for obvious physical and electrical defects such as cracked or broken parts, loose connections, bare or broken wires, loose assemblies, bent relay and switch springs, corroded jacks and plugs, and bare or cracked insulation. All defects shall be noted on an applicable data form, and corrected before proceding with the tests.

f. Prepare record forms for systematic entry of data, chronology of test, and analysis in final evaluation.

g. Prepare adequate safety precautions to provide safety for personnel and equipment, and ensure that all safety precautions are observed throughout the test.

h. Ensure that ground guidance tests are conducted on a dry clear day to avoid attenuation of high frequency radar signals by rain and moisture, and limitation of optical tracking by low lying clouds.

6.2 TEST CONDUCT

6.2.1 Maximum and Minimum Detection Ranges of Acquisition Radar

a. Calculate the theoretical maximum detection range of the acquisition radar using the equation given in paragraph 5 of Appendix A, and record on a suitable data sheet.

b. Install a variable attenuator into the input of the acquisition radar receiver

c. Adjust the variable attenuator until the maximum received signal strength of the acquisition radar indicates that the maximum detection range of the acquisition radar is within the maximum range capability of the track radar. Record the amount of attenuation inserted.

d. Utilizing a balloon, loft a metal sphere of known radius to an

altitude of 10,000 feet, and allow the wind to carry the sphere toward the acquisition and track radars.

NOTES: 1. The sphere should be released beyond the estimated detection range of the acquisition radar.
2. A suitable target aircraft of known radar cross section may be substituted for the balloon and metal sphere.

e. Acquire and track the sphere with the tracking radar and search with the acquisition radar until the sphere is detected by the acquisition radar.

f. Note and record the following information:

1) Acquisition radar range dial reading at target first detection
2) Target elevation at first detection (from tracking radar)
3) Blip/Scan ratio at first detection (See paragraph 5 of Appendix A)

g. Continue to track the incoming target with the acquisition radar until the blip/scan ratio goes below 0.5.

h. Record the following information at each 10,000 yard increment of decreasing slant range:

1) Blip/Scan ratio
2) Target elevation
3) Acquisition radar range dial reading

i. Loft the metal sphere to an altitude of 50,000 feet in increments of 10,000 feet and repeat Steps (e) thru (h), above for each 10,000 feet increment of altitude.

j. Repeat Steps (e) thru (i) above, a minimum of three times with the MTI operating and three times without the MTI operating.

k. Replace the balloon and metal sphere with a suitable target aircraft of known radar cross section (equipped with jamming equipment), and repeat Steps (e) thru (j) above, in a known jamming noise level. The target aircraft should start its flights beyond the estimated detection range of the acquisition radar.

l. Repeat Step (k) above, a minimum of three times, each time with a different type and level of jamming power.

6.2.2 Maximum Tracking Range

a. If the required tracking radar signal to noise ratio for tracking is known, calculate the maximum tracking range of the radar using the same formula as was used for maximum detection range (6.2.1), and record on a suitable data sheet.

b. If the required radar signal to noise ratio for tracking is <u>not</u> known, calculate the maximum tracking range as shown in paragraph 5 of Appendix A, and record on a suitable data sheet.

c. Fly a specific target aircraft (with a known radar cross-section) on an incoming course toward the track radar. The target aircraft should start

its flight beyond the calculated maximum tracking range of the track radar.

d. Search with the track radar until the target aircraft is detected by the track radar.

e. Determine the maximum range at which the receiver range gate can be placed around the target video pulse on the tracking scope, and manually kept around it as the video pulse moves. Record this range as the maximum manual tracking range of the track radar.

f. Repeat Steps (c), (d), and (e) above, a minimum of three times.

g. Repeat Steps (c) and (d) above.

h. Determine the maximum range at which the automatic tracking circuitry of the track radar can keep the receiver range gate around the target video pulse. Record this range as the maximum automatic tracking range of the track radar.

i. Repeat Steps (g) and (h) above, a minimum of three times.

j. Fly a suitable target aircraft, (equipped with jamming equipment) on an incoming course toward the track radar, at a known jamming noise level. The target aircraft should start its flight beyond the calculated maximum tracking range of the track radar.

k. Search with the track radar until the target aircraft is detected by the track radar. Note the maximum detection range ("burn through").

l. Record the "burn through" range.

m. Repeat Steps (j), (k), and (l) above, a minimum of three times.

6.2.3 Transfer to Track Time

a. Acquire a target, either balloon-borne metal sphere or aircraft, with the acquisition radar.

b. Start a strip recorder, stopwatch, or event recorder at the instant of first detection of the target by the acquisition radar.

c. Designate the target to the tracking radar and stop the event recorder, strip recorder, or stopwatch at the event "target-designate" (the instant of relaying the target coordinates to the tracking radar).

d. Measure and record the elapsed time between first detection of the target and "target-designate".

e. Repeat Steps (a) thru (d) above, a minimum of three times.

f. Acquire a target with the acquisition radar and designate the target to the tracking radar.

g. Start a strip recorder, event recorder, or stopwatch at the event "target-designate" and stop the recorders or stopwatch at the event "target-acquire" (the instant of "lock-on" in automatic tracking by the tracking radar).

h. Measure and record the elapsed time between "target designate" and "target-acquire".

i. Repeat Steps (f) thru (h) above, a minimum of three times.

6.2.4 Transfer to Track Accuracy

a. Acquire a slow moving target, on a radial course, with the acquisition radar and designate the target to the tracking radar.

b. Note the tracking radar azimuth dial reading when the tracking

radar acquires to the designated coordinates of the acquisition radar, and record the dial reading.

c. Note the track radar azimuth dial reading when the tracking radar begins automatic tracking, and record the dial reading.

d. Acquire a slow moving target, on a circular course, with the acquisition radar and designate the target to the tracking radar.

e. Note the track radar range dial reading when the tracking radar acquires to the designated acquisition radar coordinates, and record the range dial reading.

f. Note the track radar range dial reading when the tracking radar begins automatic tracking, and record the range dial reading.

g. Acquire a target at long slant range with the acquisition radar and designate the target to the tracking radar.

h. Note and record the track radar elevation dial reading when the tracking radar acquires to the designated acquisition radar coordinates.

i. Note and record the track radar elevation dial reading when the tracking radar begins automatic tracking.

j. Repeat steps (a) thru (i) above, a minimum of three times.

6.2.5 Quality of Target Position Information Supplied by Tracker

a. Install a phototheodolite and a corner reflector at surveyed positions and connect coded timing equipment between the theodolite and the tracking radar.

b. Install motion picture cameras with time coded film in a position to photograph the tracking radar's azimuth and elevation dials.

c. "Lay" the theodolite on the corner reflector in azimuth and elevation, and acquire and "lock" the tracking radar on the corner reflector in azimuth, elevation and range.

d. Measure and record the angular position difference between the tracking radar's electrical line-of-sight and the theodolite's optical line-of-sight (tracking bias).

e. Repeat Steps (c) and (d) once an hour for 10 hours.

f. Acquire and "lock" the tracking radar on a moving aerial target in azimuth, elevation, and range.

g. Track the same aerial target with the photo theodolite and start the motion picture cameras and time coded equipment.

h. Photograph the azimuth and elevation dials of the tracking radar.

6.2.6 Maximum Angle and Range Tracking Rates

a. Mount motion picture cameras with coded timing film in a suitable position on the tracking radar to photograph the azimuth and elevation dials.

b. Acquire and automatically track an aerial target flying a crossing course close to the radar. Start the time coded motion picture cameras.

c. If the maximum angular velocity of the target exceeds the maximum angular tracking rate of the radar, the tracking radar will lose the target. If this occurs, note at what slant range the target is lost and record on a suitable data form.

d. Acquire and automatically track an aerial target flying a radial course directly over the radar. Start the time coded motion picture cameras.

e. If the maximum angular velocity of the target exceeds the maximum angular tracking rate of the radar, the tracking radar will lose the target. If this occurs, note at what slant range the target is lost and record on a suitable data form.

f. Synchronize a pulse generator with the radar transmitter and utilize the generator to simulate a target at the RF level.

g. Vary the delay between the transmitter synchronized pulse and the simulated target pulse at a known rate to simulate a moving target in range.

h. Track the simulated pulse in automatic range tracking and note when the pulse movement exceeds the maximum range tracking rate by moving out of the receiver range gate.

i. Introduce a maximum error voltage into the range servo mechanism. The receiver range gate will move at the maximum number of yards per second on the range scope.

j. Utilizing a stopwatch, time the range tracking rate (yards per second) for 20 seconds.

k. Record the number of yards moved in 20 seconds.

6.2.7 Human Engineering

a. During conduct of paragraphs 6.2.1 through 6.2.6 above, determine if the operator's controls are adequate for the job to be done, and if they are located in logical places with respect to the operator so as to reduce his reaction time and keep his fatigue to a minimum.

b. Determine if lighting, heating, air conditioning, and operating space are adequate for proper operator performance and comfort.

c. Record all observations made during performance of Steps (a) and (b) above.

6.3 TEST DATA

6.3.1 Preparation for Test

a. Record the following:

1) Nomenclature, serial number(s), and manufacturer's name of the test item(s).
2) Nomenclature, serial number, accuracy tolerances, calibration requirements, and last date calibrated of the test equipment selected for the test.
3) Discrepancies and deficiencies noted in equipment inspection prior to start of the test.

6.3.2 Test Conduct

6.3.2.1 Maximum and Minimum Detection Ranges of Acquisition Radar

a. Record the calculated theoretical maximum detection range of the acquisition radar.

b. Record the amount of attenuation inserted in the acquisition radar receiver.

c. Record the following information at first target detection:

1) Acquisition radar range dial reading
2) Target elevation (from track radar)
3) Blip/Scan ratio

d. Record the following information at each 10,000 feet of decreasing slant range for each 10,000 feet increment of altitude:

1) Blip/Scan ratio
2) Target elevation
3) Acquisition radar range dial reading

e. Record each type and noise level of jamming

6.3.2.2 Maximum Tracking Range

a. Record calculated maximum tracking range and whether the signal to noise ratio is known or unknown.

b. Record maximum manual tracking ranges.

c. Record maximum automatic tracking ranges.

d. Record "burn through" ranges.

6.3.2.3 Transfer to Track Time

a. Record times from first detection to "target-designate".

b. Record times from "Target-designate" to "target-acquire".

6.3.2.4 Transfer to Track Accuracy

a. Record azimuth dial reading when track radar acquires to designated acquisition radar coordinates.

b. Record dial reading when track radar begins automatic tracking.

c. Record range dial reading when track radar acquires to designated acquisition radar coordinates.

d. Record range dial reading when track radar begins automatic tracking.

e. Record elevation dial reading when track radar acquires to designated acquisition radar coordinates.

f. Record elevation dial reading when track radar begins automatic tracking.

6.3.2.5 Quality of Target Position Information Supplied by Tracker

a. Record tracking bias in azimuth and elevation of track radar on corner reflector

b. Record tracking bias in azimuth and elevation of track radar on aerial target.

6.3.2.6 Maximum Angle and Range Tracking Rates

a. Record slant range at which target is lost in azimuth.
b. Record slant range at which target is lost in elevation.
c. Record the number of yards the range moves in 20 seconds.

6.3.2.7 Human Engineering

a. Record all pertinent observations made during performance of ground guidance system tests.

6.4 DATA REDUCTION AND PRESENTATION

6.4.1 Data Reduction

6.4.1.1 Maximum and Minimum Detection Range of Acquisition Radar

a. Plot a bar graph as shown in Figure 1, showing maximum detection range versus blip/scan ratio for each increment of altitude of each test condition. The graph should show target slant range on the x-axis and blip/scan ratio on the y-axis.

b. Plot a detection range contour as shown in Figure 2, showing acquisition radar detection range for each test condition. The graph should show target slant range on the x-axis and target altitude on the y-axis.

6.4.1.2 Maximum Tracking Range

a. Calculate the average maximum manual tracking range.
b. Calculate the average maximum automatic tracking range.
c. Calculate average "burn through" range.

6.4.1.3 Transfer to Track Time

a. Calculate the average elapsed time from first detection of the target to "target-designate".

b. Calculate the average elapsed time from "target-designate" to "target-acquire".

6.4.1.4 Transfer to Track Accuracy - Calculate the average difference between the designated coordinates and the actual coordinates.

6.4.1.5 Quality of Target Position Information Supplied by Tracker -

Determine the standard deviation of angle tracking error (bias) by comparing the time coded optical data obtained from the theodolite with the time coded photographs of the azimuth and elevation dials of the tracking radar.

6.4.1.6 Maximum Angle and Range Tracking Rates -

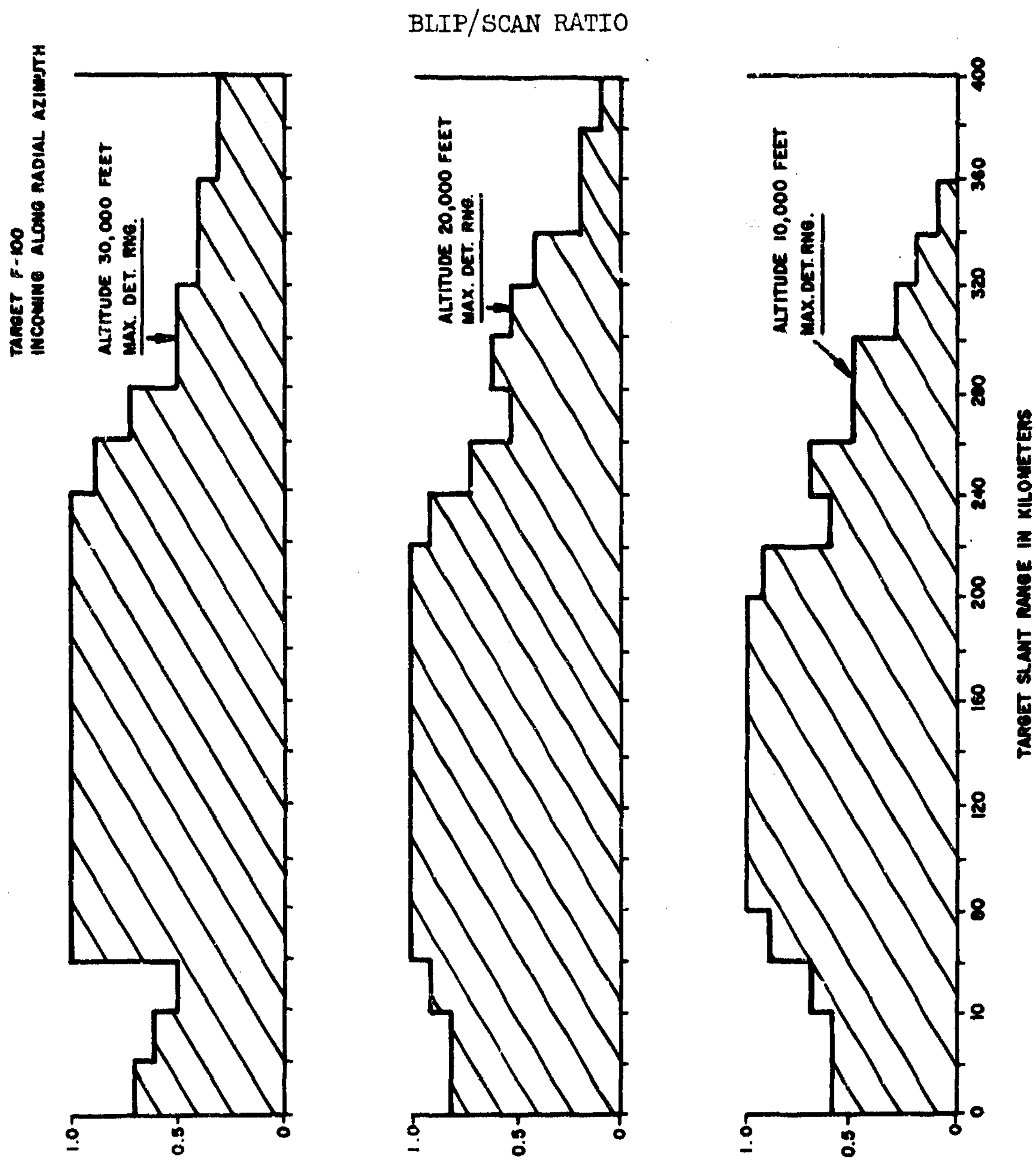

Figure 1. Typical Maximum Detection Range Graphs

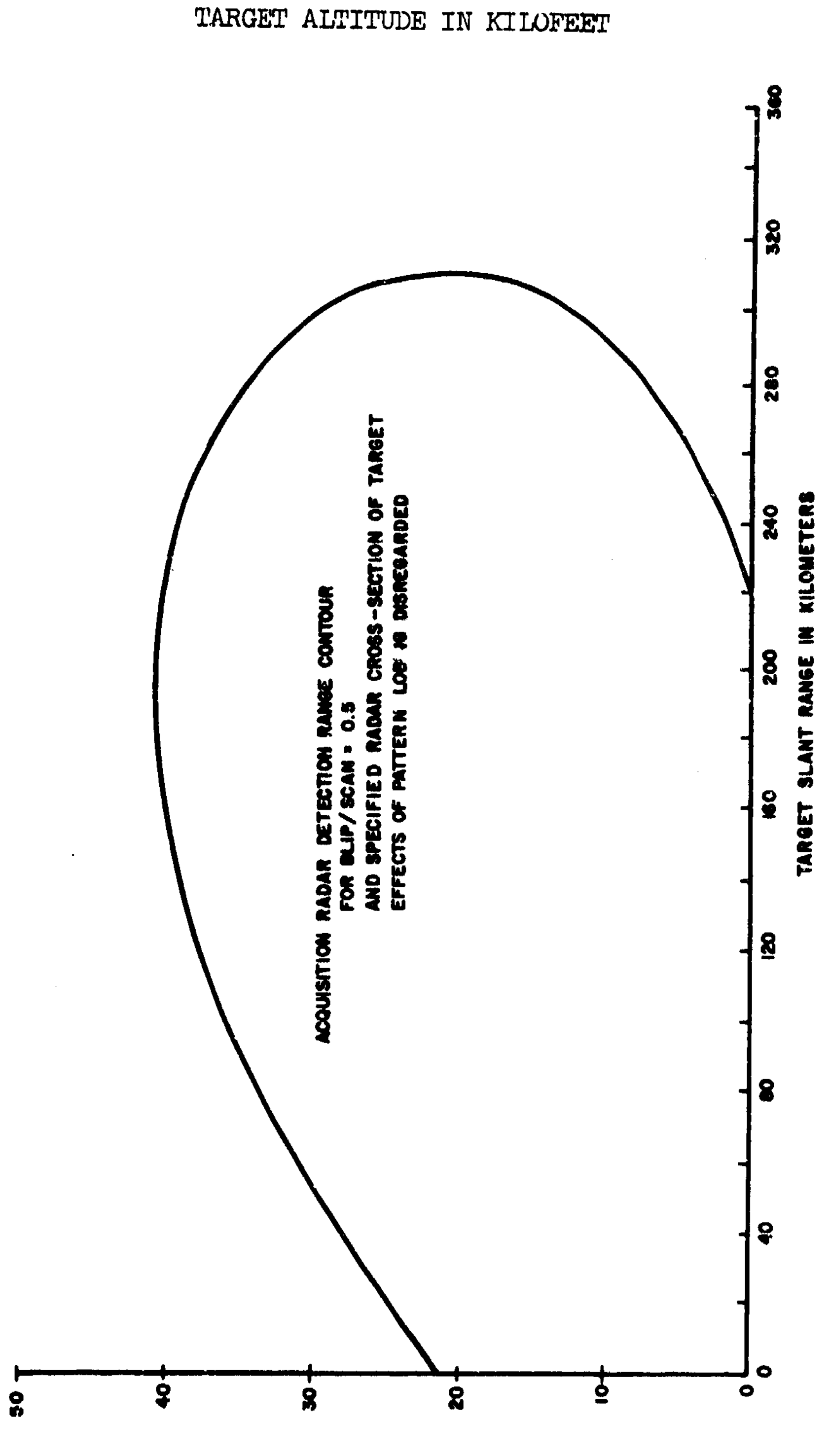

Figure 2. Typical Acqusition Radar Detection Range Contour

a. Calculate the angular velocity in azimuth and elevation of the target relative to the radar at the instant of loss of target.

b. Determine the maximum azimuth and elevation tracking rates of the radar, utilizing the time coded photographs of the azimuth and elevation dials.

c. Calculate the maximum range tracking rate of the radar by the yards per second movement of the range gate and time (20 seconds).

6.4.1.7 Human Engineering - Compare observations made during performance of ground guidance system tests with accepted standards of human engineering.

6.4.2 Presentation

Processing of raw subtest data shall consist of organizing the data under the appropriate subtest title. All test data shall be properly marked for identification and correlation to the test item in accordance with paragraph 6.3 as a minimum.

A written report shall accompany all test data and shall consist of conclusions and recommendations drawn from test results. The test engineer's opinion, concerning the success or failure of any of the functions evaluated, shall be included. In addition, equipment specifications that will serve as the model for a comparison of the actual test results should be included.

Equipment evaluation usually will be limited to comparing the actual test results to the equipment specifications and the requirements as imposed by the intended usage. The results may also be compared to data gathered from previous tests of similar equipment.

APPENDIX "A"

GROUND GUIDANCE SYSTEM TESTS

1. GENERAL

Ground guidance equipment may be required to perform any or all of the following functions:

a. Detection of targets.
b. Identification of potential targets as friends or foes and selection of some target for interception.
c. Acquisition of target with a target tracker.
d. Monitoring target position (or direction) with the tracker.
e. Prelaunch computations.
f. Selection of missile to be launched and issuing launch command.
g. Post launch computations and issuing of commands to missile.
h. Monitoring position of intercepting missile and issuing burst commands.

The Missile system must be evaluated in terms of how well it can perform its intended role when confronted with the various tactical situations available to the enemy. The ground guidance portion of the missile system must be evaluated in terms of how well it enables the overall system to fulfill its intended function. The limiting bounds and other restrictions which the ground guidance portion imposes on the overall system must be found by testing and evaluation. Once certain limitations have been determined as a result of evaluation or analysis of test data, it must then be determined whether these limitations are acceptable. If they are unacceptable, a recommendation is made as to whether the equipment should be rejected or redesigned to remove or reduce its limitations to an acceptable value.

For a full understanding of the ground guidance system, the general functions of the acquisition radar, the track radar system, and the computer are described below.

2. ACQUISITION RADAR

Detection of targets usually is accomplished by means of search radars which periodically scan large volumes of space and display objects which reflect radar energy. Scanning may take place over 360°, or sector scanning may be used. The search radar is called an acquisition radar if it is used to position a tracker on the target. Target detection can also be carried out with wide angle optical instruments or infrared detectors. The desirability of detecting targets at long ranges and in day or night results in most surface to air (SA) guided missile systems using an acquisition radar to perform the target detection function. Acquisition radars usually are equipped with moving target indicators (MTI) which cause radar returns from moving targets to stand out better than radar returns from fixed objects. Many are also equipped with electronic counter countermeasures (ECCM) devices to improve the operator's chance of detecting targets in the presence of enemy electronic countermeasures (ECM).

Tests on the acquisition radar are designed to reveal how well an acquisition radar can detect different types of targets in various kinds of environments. They are designed to show:

a. Maximum and minimum detection ranges versus target type, target velocity, and target attitude
b. Effect of ground clutter level (reflections from fixed objects) on ability to detect targets
c. Effect of various kinds of electronic jamming on detection range
d. Effectiveness of available ECCM devices and techniques

3. TRACKING RADAR

Acquisition of the target by the tracker usually is accomplished by supplying two or three target coordinates to the tracker from the acquisition device. If radars are used to perform the search and tracking functions, the acquisition radar may supply the azimuth and slant range of the target. The track radar pencil beam is then swept up and down a few degrees in elevation angle until a target return signal is observed. Some acquisition radars are designed to supply all three target coordinates (azimuth, elevation, and range), to the tracker.

Once the target tracker acquires the target, it continues to track it either by manual or automatic means. Target position (or direction) obtained by the target tracker is used to guide the missile to the target. Command guidance systems may use a separate tracker for following the missile. A homing system will not require a missile tracker but will require a target tracker to illuminate the target. The target tracker tracks on reflected energy (two-way), while the missile tracker uses transponder inputs (one-way).

Tests on target (or missile) trackers are designed to reveal:

a. Maximum and minimum tracking ranges for various types of targets flying at selected altitudes and in selected environments
b. Quality of position information supplied by tracker (accuracy and roughness of tracking)
c. Maximum angle and range tracking rates
d. Maximum "lock on" range (for homing missile)
e. Effect of ECM on tracker performance
f. Effectiveness of ECCM devices and techniques against various kinds of ECM
g. Ability of missile track radar to lock onto transponder return and stay locked on when missile is launched or maneuvered
h. Adequacy of operators' controls and living environment (evaluation of human engineering)

4. COMPUTER

A computer may be used for prelaunch computations such as location of the predicted intercept point. This computation may be used for orientation of the missile launcher (or a roll gyro in the missile) to cause the missile to head toward a predicted intercept point. Of course the missile would not be

launched until the predicted intercept point is within range of the intercepting missile. The predicted intercept point location may also be used to program commands to the missile to optimize the trajectory. The latter is important in that it has a bearing on the rate of fire of the missile system.

After the intercepting missile is launched, a command guidance system uses a computer to compute guidance commands. Burst commands may also be used if a proximity fuze is not employed.

5. RADAR TESTS OF GROUND GUIDANCE SYSTEMS

a. Maximum and Minimum Detection Ranges of Acquisition Radar Test

The maximum detection range of an acquisition radar depends on such factors as:

1) Peak transmitted power
2) Antenna gain in direction of target
3) Effective area of receiving antenna in direction of target
4) Radar cross-section of target
5) Noise figure of receiver
6) Extraneous noise such as ground clutter or jamming in the receiver bandwidth and thermal noise at input of receiver in its pass band
7) Signal processing features of the receiver which aid in improving the signal power-to-noise power ratio at the input to the display oscilloscopes
8) Attenuation of signal power due to atmospheric effects

It is readily seen from the above variables that quoting a maximum detection range means little unless the conditions under which that range can be achieved are also specified, (See MTPs 5-2-530, 5-2-529, and 5-2-518).

The maximum detection range against a target of known radar cross-section in a clear environment (no jamming, no ground clutter) can be calculated, if systems parameters are known, by use of the radar range equation given below:

$$R_{max} = \left[\frac{P_t\, G_t\, G_r\, \lambda^2\, A_t \times 10^{-.2\sigma R}}{(4\pi)^3 (K\,T\,B)\,(N.F.)(S)F^2} \right]^{1/4} \text{ meters}$$

where:

P_t = peak transmitted power in watts

G_t = gain of transmitter antenna in direction of target

G_r = gain of receiver antenna in direction of target

λ = wavelength in meters

A_t = radar cross-section of target in square meters

σ = one-way attenuation of atmosphere in db/meter

KBT = thermal noise power in receiver pass band in watts

N.F. = receiver noise figure expressed as a factor

S = ratio of signal power required for detection to noise power in receiver pass band. It is a factor whose value depends on the desired probability of detection and the receiver processing circuitry.

F = propagation factor to take into account lobing caused by interference of reflections from ground surface. (G/F is the effective gain. Gain will be minimum at elevation angles corresponding to $\tan^{-1} H/D = \tan^{-1} n\lambda/2h$ where H = target height above plane surface, D = horizontal range to target, n = an integer, λ = wavelength, h = height of center of antenna. Gain is maximum at elevation angles intermediate from above.

Maximum detection range for a known radar cross-section target is found by lofting metal spheres of known radius with balloons and allowing the wind to carry the spheres toward the acquisition radar. The spheres should be released at a range beyond the presentation range of the acquisition radar or at least beyond the estimated detection range. It is convenient to place an attenuator in the input of the receiver to reduce the effective cross-section Once this detection range has been determined it is a simple matter to compute the detection range for the full size sphere or any other target of known radar cross-section. This technique allows the balloons to be released closer to the acquisition radar and also allows the sphere to be tracked with a tracking radar.

Detection range is also a function of elevation angle due to directivity of antenna, i.e., antenna pattern. The elevation angle to the target sphere at the detection range may be determined with a tracking radar. If the attenuator is not used in the acquisition radar receiver, its detection range will probably exceed the tracking range of the associated tracking radar and the elevation angle at the range of detection will have to be estimated by extrapolation of track radar data. This method is subject to more error so it is recommended that a known attenuator in the acquisition radar receiver be used for the maximum detection range test.

A target will not appear on the presentation oscilloscope every time the acquisition radar beam scans across the target due to flunctuations in the radar return signals being received. These fluctuations are due to fluctuating cross-section (except when spheres are used), interference from ground reflections and changing position of target in antenna pattern. Each time the target appears on the display scope it is called a "blip". The ratio of the number of

blips to the number of times the radar beam scans across the target is called the blip/scan (B/S) ratio. The blip/scan ratio is closely related to probability of detection. It is convenient in experimental work to define the maximum detection range as the range at which a specified blip/scan ratio is obtained. An appropriate value is 0.5.

Maximum detection range versus elevation angle is now obtained by allowing the target (either sphere or type of aircraft) to approach the radar at various altitudes and obtaining a blip/scan ratio for selected increments of slant range. Bar graphs can be plotted for each altitude from these data. These graphs may be used to plot a detection range contour.

As the target approaches from a range greater than the detection range, the b/s ratio will continue to improve and after it is within detection range, a blip on each scan (b/s = 1.0) will be a common occurence. As the target gets close to the radar, ground clutter (reflections from fixed objects and terrain) may begin to obscure the target and the b/s ratio will start to fall off. Also, the fan beam of the acquisition radar is configured in a manner that affects blip/scan ratio for close in targets since it generally does not cover from 0° - 90° elevation. Therefore, minimum detection range can be defined as the range at which the b/s ratio goes below 0.5.

Most acquisition radars have moving target indicators to reduce the effects of ground clutter. A moving target indicator may slightly reduce the maximum detection range and eliminate the minimum detection range. Therefore, the maximum and minimum detection ranges should be determined both with and without the MTI. Similarly, this test should be performed for different types and levels of jamming power. The quoted detection range should be one that represents the average of several measurements. Any one measurement may differ from the quoted detection range by as much as 20 percent.

b. Maximum Tracking Range Test

The technique for measuring maximum tracking range is similar to that for determining the maximum detection range except for the following differences:

1) The track radar has a pencil beam instead of a fan beam and the target is kept in the center of the beam. Hence, the antenna gain in the direction of the target is constant and equal to the maximum gain. The effects of a variable gain in the target direction need not be considered as it was with the fan shaped beam of the acquisition radar.

2) The criterion for maximum tracking range is different. Maximum manual tracking range is defined as the maximum range at which the receiver range gate can be placed around the target video pulse on the tracking scope, and manually kept around it as the video pulse moves. Maximum automatic tracking range is the maximum range at which the automatic tracking circuitry can keep

the receiver range gate around the target video pulse.

3) Maximum tracking range of a known radar cross-section target can be determined using an outgoing target. However, maximum tracking range on a specific type of target with a known radar cross-section should be determined for an incoming target since radar cross-section varies with aspect and, in practice, it is more likely that an intercept attempt will be made on an incoming target.

Maximum tracking range of the track radar can be calculated from the same type of formula as was used for maximum detection range if the required signal to noise ratio for tracking is known. An alternative approach is to measure the minimum detectable signal power of the track radar receiver and plot a curve of received radar power versus slant range. The range at which the received power equals the minimum detectable signal power is an approximation of maximum tracking range. If atmospheric attenuation is neglected, the received power versus range curve will be a straight line with a slope of 40 db per decade or approximately 12 db per octave when plotted on semi-log paper. That is, the received power will decrease 12 db each time the range is doubled. If atmospheric attenuation is included, the curve will deviate more and more from a straight line as range increases. An empirical value for atmospheric attenuation at X-band in clear weather which agrees well with experimental data is 0.02 db/kilometer. Rain will attenuate the signal. The degree of attenuation is a function of the density of rainfall. See Figure A-1 for sample calculation of maximum range.

This test should also be carried out in a known jamming noise level. When this is done, the maximum range is known as "burn through" or "self screening" range. The maximum quoted track radar acquisition range for a given target should be determined by averaging several measured values. The maximum range achieved in any one measurement may differ from the quoted range by as much as 10 percent.

c. Transfer to Track Time Test

Transfer to track time is the average time required for the track radar to acquire the target in azimuth, elevation, and slant range. It is measured from the instant the acquisition radar operator relays some of the target coordinates to the track radar. It is important to keep this time to a minimum to reduce the time required to carry out an intercept. This is a simple test which may be carried out with a stopwatch or a strip recorder. In the later case, it is necessary to record timing marks and the times of two events, target-designate and target-acquire. A similar test may be devised to measure the "designate time". This is the time interval between first detection of a target on the acquisition radar and the instant some of the coordinates are relayed to the track radar. The combination of these times gives the interval from "detection" to "acquire".

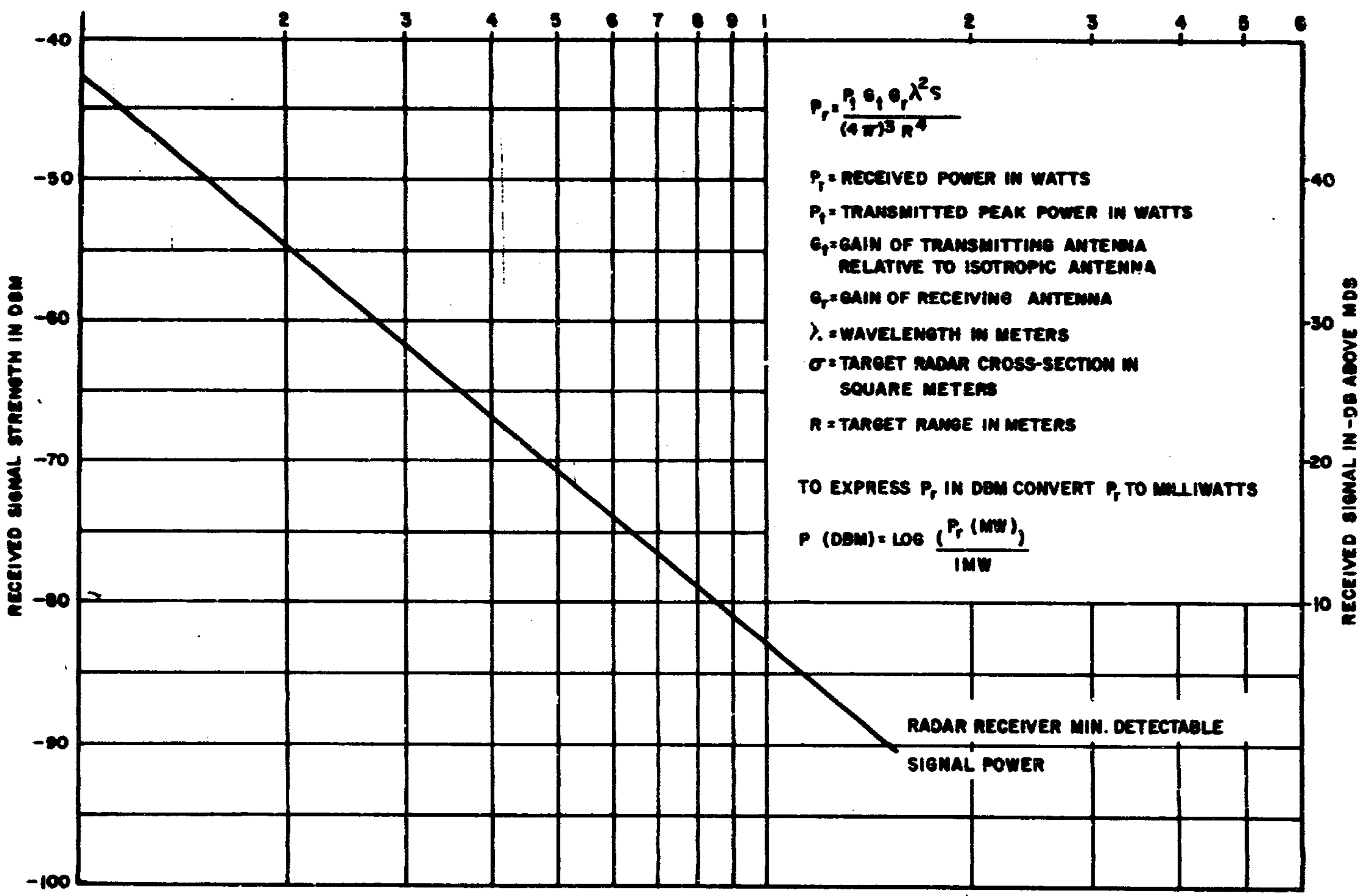

Figure A-1. Typical Received Radar Power Versus Target Slant Range Curve

d. Transfer to Track Accuracy Test

This test reveals the accuracy with which the acquisition radar operator can relay the target coordinates to the track radar. If azimuth, elevation, and range are designated (or any two of these three coordinates), the difference between the designated coordinates and the actual coordinates is a measure of the transfer to track accuracy. The designated coordinates are obtained (usually from dial readings) when the track radar acquires to the designated acquisition radar coordinates. The actual coordinates are obtained after the track radar begins automatic tracking. Effect of target motion during the transfer to track time can be kept to a minimum by using a slow target on a radial course for measuring accuracy in azimuth and a circular course for measuring accuracy in range. If the track radar also acquires in elevation angle from the acquisition radar the elevation effect of target motion on it can be kept to a minimum by performing the transfer at long slant ranges.

Jamming will affect the accuracy to some extent. Accuracy required will depend on the field of view (or beam width) of tracker. For a radar tracker, the beam should be directed accurately enough to place the target between the half-power points.

e. Quality of Target Position Information Supplied by Tracker Test

Quality of target position information involves two factors; bias and amount of fluctuation about the bias. Automatic trackers must lag the target in range and angle to develop an error which will cause the tracker to follow the target. The average error is called tracking bias. If the tracker is positioned by servos, it likely will oscillate back and forth across the target. The standard deviation of the instantaneous values of azimuth angle with respect to the azimuth bias value is a measure of the smoothness of tracking in azimuth. The same applies to elevation angle and slant range. In general, tracking will be smoother when the signal-to-noise ratio is high, except for cases when the target is so close that it is no longer a point target and the radar sees the signal reflected from different parts of the target. That is, the center of reflectivity will change for a target at close range and this will cause more fluctuation in the azimuth, elevation, and range coordinates. Tracking also will be rough for targets which are so far out in range that the radar return is only one or two decibels above receiver noise. There will be an optimum range for a target of given radar cross-section.

Tracking bias is determined by comparing the true target position with the position in which the radar sees it. True target position must be determined from some independent source which is acceptable as a standard of comparison. Target position obtained with optical instruments located at surveyed positions is accurate to within a few feet and may be used as a standard. Of course coded timing must be used with both the optical data and radar data in order for them to be correlated. Boresight film may also be analyzed for a bias value.

Target bias and smoothness of tracking are particularly important in command guidance systems since they largely determine the miss distance when an

intercept is carried out.

A close approximation of error in target position due to error in azimuth angle is given by RA where R equals slant range and A equals azimuth error in radians. The same holds true for elevation angle and at low elevation angles the errors will be almost orthogonal to each other while an error in slant range is almost orthogonal to the above two errors. Error in target position is given by the square root of the sum of the squares of the individual errors. At higher target elevation angles, the errors will not be orthogonal. Conversion factors are: 1 angular mil = 0.05.625° = 0.00098175 radian.

Bias in position of a stationary target can be measured by using corner reflectors at surveyed positions relative to the tracking radar. The survey determines the true azimuth, elevation, and range which serves as the standard of comparison. Large errors are often attributable to refraction of the radar beam which may vary from hour to hour.

Standard deviation of angle tracking error may be obtained by analyzing boresight film on a frame by frame basis or at fixed time intervals. If the tracking radar is equipped with dials showing the azimuth and elevation angle, these dials may be photographed and the standard deviation obtained from them.

In the final analysis, however, overall system accuracy must be demonstrated by carrying out actual intercepts and measuring the miss distance by optical means. Position of burst relative to target should be expressed in three coordinates as well as in terms of radial miss distance because the direction of miss is important when one considers the directional characteristics of the warhead.

f. Maximum Angle and Range Tracking Rates Test

A target flying a crossing course close to the radar will result in a high angular velocity. A low altitude 500-yard/sec target flying on a crossing course which places it 500 yards from the radar at its closest approach results in a maximum azimuth angular velocity of 1 radian/sec or 1020 mils/sec. If the maximum angular tracking rate is less than 1020 mils/sec, the tracking radar will lose the target at some slant range and the angular velocity of the target relative to the radar at that instant can be calculated. Azimuth dial photography with coded timing may also be used to determine the maximum azimuth tracking rate. The same technique can be used for determining maximum elevation angle tracking rate except the target should fly on a radial course directly over the radar. Maximum range tracking rate should be obtained with a simulated target pulse if possible. A pulse generator which is synchronized with the radar transmitter may be used to simulate a target at either the RF or IF level. Varying the delay between the transmitter synchronizing pulse and the simulated target pulse at a known rate will simulate a moving target. Alternative methods are as follows:

1) A given range rate may also be set into the range servo by introducing a known error voltage. The receiver range gate

will then move at a certain number of yards per second on the range scope. The latter may be determined by a stop watch and the known range scales on the scope (yards per inch). The error voltage may be progressively increased until the maximum rate of range gate movement is obtained. The same technique can be used with the azimuth and elevation servos.

2) Accuracies of 5 percent in maximum angle tracking rate are sufficient in most cases. The same accuracy is sufficient for maximum range rate.

g. Human Engineering Test

Human engineering features which have been designed into a system must be considered in an overall evaluation of the system. Effectiveness of the acquisition and track devices is governed in part by the human engineering features which have been designed into the system. Determine if the controls are adequate for the job to be done, if they are located in logical places with respect to the operator so as to reduce his reaction time and keep his fatigue to a minimum, if lighting, heating, air conditioning and operating space are adequate. These largely are determined by "on site" observations of operator performance and comfort. Refer to the applicable MTP for detailed tests in the area of human engineering.

GLOSSARY

1. Phototheodolite: An arrangement of two telescopic cameras the plates of which may be brought into exactly the same plane. From the differences between the two pictures taken at the same instant, measurements in all dimensions of the target may be obtained.

2. Propagation Factor: The ratio of the amplitude of the electric field at a given point under specified conditions to the amplitude of the electric field under free space conditions with the beam of the transmitter directed toward the point in question.

3. Proximity Fuze: A miniature transmitter-receiver (or merely receiver) device, used in artillery shells, bombs, and rockets, which trips the firing mechanism when the armed projectile approaches within a predetermined distance of the target.

4. Radar Beam Refraction: A deflection from a straight path of the radar beam due to inequalities of atmospheric densities which results in a false target position indication by the radar receiver.

5. Blip/Scan Ratio: The ratio of the number of blips to the number of times the acquisition radar beam sweeps across the target. The blip/scan ratio is closely related to probability of detection.

6. Burn Through Range: The maximum detection range of a target in a known jamming noise level.